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ON THE DURATION OF WIDESPREAD FOG AND LOW CEILING IN CENTRAL EUROPE AND SOME ASPECTS OF PREDICTABILITY

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Army Missile Command
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The duration of adverse weather over Central Europe has been analyzed. After a definition of adverse weather, the duration in hours and days is given. While the median of the frequency for the hours fluctuates between 4 to 8 hours in winter at a single station, the duration in days ranges in the average between 2 and 3 hours. In 10 percent of the cases, adverse weather exceeds between 16 to 24 hours, while 10 percent of the cases lasts more than 4 to 7 days in the winter months. Station combinations to assess the duration of adverse weather over an extended area provide the same result in days. The difference is the number of total cases. They decrease with increasing areal extent of the station network.

Also in this report, the probability chances for a successful prediction of adverse weather are evaluated. Several models have been considered and speculative numbers were obtained. Evaluation is based on the large-scale weather patterns over Central Europe [Grosswetterlagen (GWL)] and their relationship with adverse weather. It has been demonstrated that the best 1-day prediction chances appear on the second day of some GWL types, but in general the 1-day chances are high due to prediction of large-scale phenomena in contrast to the local scale. As expected, the medium range prediction chance decreases with an increasing time interval from the prediction point but may be of the same magnitude up to the fourth day as today's local forecast scores.

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CONTENTS

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Section I. INTRODUCTION

In a previous study [1] the probability of limited visibility and low ceiling over an areal extent in Central Europe was assessed. As concluded, the chances of widespread fog and/or low ceiling of defined class boundaries were 5 percent in the morning hours of the winter months. The requirement placed was so that all of the area comprising six observational points had to show the adverse weather conditions. When this restriction was relaxed to four out of six stations, the frequency of occurrence went up to about 20 percent in winter. This constitutes a considerable fraction of the month and warrants some closer perusal of the duration and predictability of these adverse conditions.

In the field of duration, a two-folded interest exists. First, one likes to know the duration in hours. It was pointed out in the above referenced report that in the winter months the majority of cases will exceed 3 hours. This can be confirmed by the results of this study. In fact the median (50-percent probability) fluctuates between 4-1/2 to 8 hours in winter for selected individual stations.

The second problem is the number of days the adverse weather will last. While the time occurrence in hours can be readily given, the duration in days requires some definition. Should an adverse condition starting at 9 p.m. and lasting until 6 a.m. of the next day be counted as 2 days or only as one event. This question will be discussed in detail in Section II.4. It may be added here that the definition is not a critical factor and the median duration ranges between 2 to 3 days in the winter months.

The extended duration of the adverse weather condition in hours as well as in days has considerable impact on the predictability of these conditions. By and large, it is more difficult to predict events which have a relatively short duration compared with the prediction interval. This statement will be more elucidated in Section III.

The predictability chances are also influenced by the areal scale of interest. While it may be extremely difficult to give an accurate prediction for an individual location, the forecast of a large scale weather pattern or an event over a certain area will have a higher score of success. This fact will also be explained in more detail in Section III.

Although the success chances of forecasting limited visibility and/or low ceiling can only be correctly assessed if the method or model for prediction is known, some speculative figures are compiled on account of duration and occurrence of adverse weather conditions associated with certain types of large scale weather pattern. The details can be found in the subsequent sections.

The data on which this study is based were essentially the same as in the previous report. These data are listed in Table 1.

TABLE 1. LIST OF STATIONS

Station	Station Code	Period of Record	N
Hannover	10338	1 Jan 49 - 31 Dec 58 1 Aug 59 - 30 Nov 71	88876
Hof	10685	1 Jan 49 - 31 Dec 59 1 Aug 59 - 30 Nov 71	45099
Stuttgart	34041	1 Oct 46 - 31 Dec 70	212211
Heidelberg	34046	18 Nov 46 - 31 Jul 47 1 Apr 54 - 31 Dec 70	149994
Bitburg	34049	1 Apr 52 - 31 Dec 70	159691
Hahn	34055	23 Jul 53 - 31 Dec 70	151213
Sembach	34056	1 Jul 53 - 31 Dec 70	141517
Fuerstenfeldbruck	34178	24 Jul 46 - 31 Oct 57	97824
Grafenwoehr	34189	2 Jan 59 - 31 Dec 70	87613
Frankfurt/Main	35032	1 Sep 46 - 31 Dec 70	203166
Fulda	35053	3 Sep 60 - 31 Dec 70	58841
Berlin (Tempelhof)	35104	1 Apr 46 - 31 Dec 70	216786

Section II. DURATION OF ADVERSE WEATHER

1. Definition of Adverse Weather

Before any study of the duration of adverse weather can be made, the expression "adverse weather" must be defined. This definition will vary with the problem involved. While the layman may understand rain or storm as an adverse condition, the definition here is based on visibility and clouds.

The duration of an event depends even in the one-element case strictly on the chosen threshold. In the two-element case this boundary is so much more important such as it is the case here.

In the previous task [1] four categories of weather situations had been selected. These categories were presented in Reference [1] and have been adopted here. Table 2 shows the four main types with Roman numbers and the respective subtypes with letters. Most of this study is based on the main types, I through IV.

The discussion of the detailed class division is of negligible importance here, and the reader may refer to the above mentioned report for more details. The characterization of the four main types is given in Table 2.

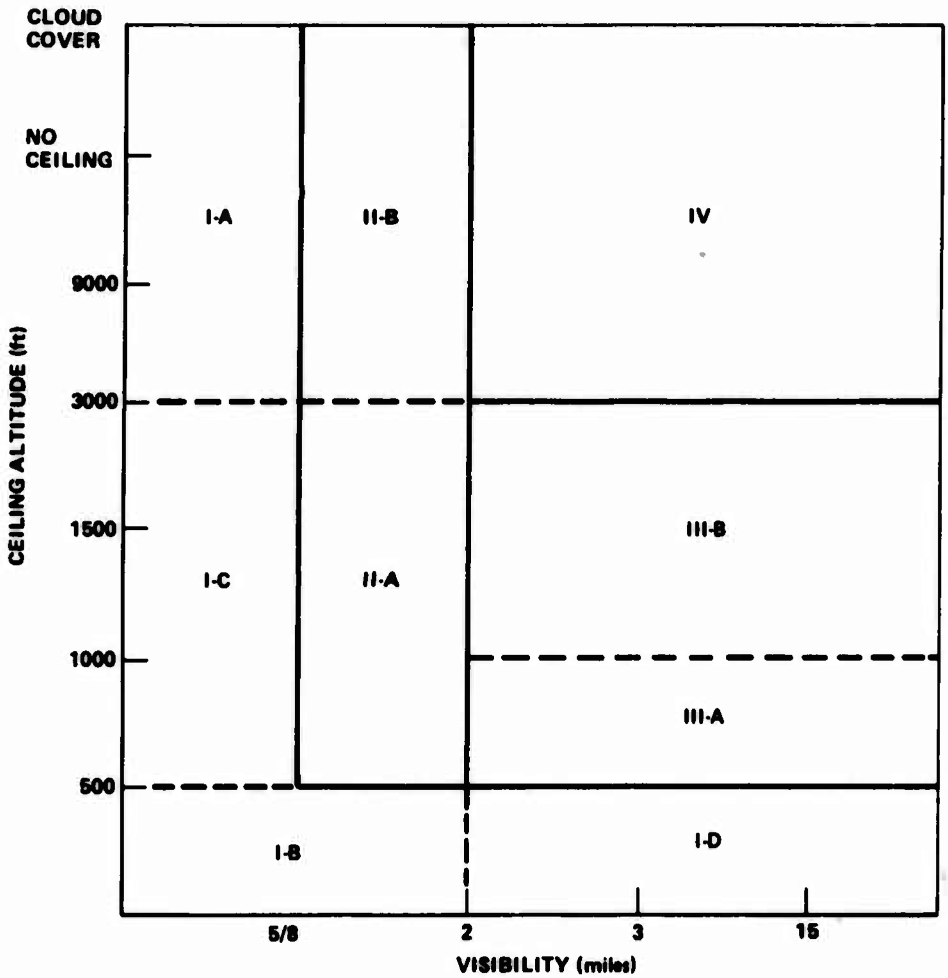
2. Statistical Representation of Durations

While the empirical frequency distributions of the durations of adverse weather (e.g., type I) for a specified time period such as number of hours of days can be very instructive, detailed tables of these have the disadvantage that evaluation and comparison cannot readily be made because the tables are too voluminous. Statistical parameters or cumulative thresholds must, therefore, be selected.

The mean value, although best known and in widespread application, loses some significance when the distribution is non-Gaussian as is the case here. The median is, therefore, a better parameter for the purpose of our evaluation. Although this median could be determined from the empirical data, the process is elaborate and time consuming. In addition, other cumulative thresholds, especially towards the extreme ends of the frequency, may be influenced by too much random fluctuation within the empirical data. A balancing and reducing of the random error by an analytical model is, therefore, highly desirable.

Also the usual interpretation of the cumulative thresholds in terms of the standard deviation is not applicable since the distribution model is non-Gaussian as previously stated. A frequency model was, therefore, selected in the Weibull distribution for its flexibility and adjustment to various forms. The cumulative distribution can be written as

TABLE 2. CONTINGENCY TABLE OF MAJOR WEATHER TYPES AND SUBGROUPS



I – FOG AND LOW CLOUDS
II – HAZE
III – OVERCAST
IV – CLEAR

$$F_{(x)} = 1 - \exp\left[-\left(\frac{x-\gamma}{\theta}\right)^{\beta}\right] \quad (1)$$

where γ, β, and θ are parameters of the model.

Since maximum likelihood estimators for fitting the three-parameter model are costly in computations a moments fit as developed by the author [2] has been employed. This requires only the calculation of the first three moments of the data which is a trivial and inexpensive task. More details can be found in Reference [2].

The establishment of a model has one other advantage. The distribution of durations had to be determined from three hourly observations only. This restraint was necessary for cost reduction, the short deadline for this study, and limitations of the observational data to 3 hours for some of the individual stations. The model made it possible, however, to determine an approximate value other than multiples of 3 hours, which would have been very difficult to obtain from the discontinuous frequency distribution of empirical data alone.

3. Duration by Hours

In the study of duration of adverse weather of hours length, it was relatively easy to make a decision for an hour with type I weather as the data were available at three hourly steps on the hour. Two consecutive hours were rated as 3 hours, giving a class interval from 1.5 to 4.5 hours length in the Weibull frequency. With an exponential decline of the frequency towards longer duration, the assumed central class value of 3 hours and subsequent class intervals of 3 hours is slightly overestimating this value. It balances out to some extent in the Weibull model and the cumulative thresholds fall within the usual limits of the statistical error. The cases with less than 1-hour type I weather were of secondary interest and were counted with no type I weather. They were separated from the collective because the main interest here was the treatment of adverse weather of more than 1-hour duration. The subsequent tabulations are, therefore, only valid for the consideration when type I weather of more than 1 hour exists and does not include all cases with other type weather or all the hours.

This practice is equivalent to the study of the duration of an event of a certain threshold such as the existence of a temperature over 100°F, where the postulation is made that the event has taken place without reference to the cases when the event does not occur. It is evident that an expansion could have been made to include all cases, but it was of secondary interest here.

The subsequent study is based on three hourly records with fitting of a Weibull model type frequency. Tables 3a and b display the results for five selected stations by months. These stations were depicted to display the dispersion within the area of Central Europe.

First, the mean and the maximum duration in hours is given in Table 3a. As expected most stations discern a peak in the winter months and a low in the summer. The exception is Hof, which was chosen for that reason. Its orographic position in an enclosed valley causes a crest of the duration of type I weather in early summer (June) which is even higher than the winter peak. This longer duration in summer runs parallel with a secondary peak of the maximum duration in May and June, but the main peak for maximum hours can be found in the winter months similar to the other stations.

As exhibited in Table 3a, the average duration of type I weather ranges from about 8 to 12 hours in the winter months. It should be added, however, that the distribution form is non-Gaussian, and the median (50-percent value), as shown in Table , is lower, namely between 5 to 8 hou· .

The maximum duration (in multiples of 3 hours) crests in the winter months for all five stations although the peak varies from November to February at the individual station. Again, a wide dispersion between the individual stations can be found, from a low of 51 hours at Hannover to a high of 114 hours at Hof.

Besides the 50-percent value of the cumulative distribution the 90-percent threshold is given in Table 3b. This 90-percent cumulative threshold corresponds to duration lengths of type I weather which are exceeded 10 percent of the time. The threshold in hours is furnished by Table 3b. As we learn in the winter months, 10 percent of the cases last longer than 14 to 16 hours, at some particular station even longer than 1 day. This extended duration gives excellent opportunity for proper prediction.

The last section of Table 3b lists the number of individual cases of type I weather. One may expect that the more individual cases exist, the shorter their duration would be, but this is erroneous. We notice also that the summer maximum of the length of type I weather does not automatically make Hof the station with the highest average or median.

In summary one may deduct from Tables 3a and b that in one-half of the cases the duration of type I weather is longer than 5 to 8 hours and in 10 percent of the cases longer than 14 to 16 hours in the winter months. The interpretation of the tabulations for the individual stations must include the study of the orographic condition and geographic location of the station and may not be pursued in detail here.

TABLE 3a. MEAN AND MAXIMUM DURATION OF TYPE I WEATHER (HOURS), 1949–1970

Month	Mean					Maximum				
	Hannover	Hof	Stuttgart	Bitburg	Berlin	Hannover	Hof	Stuttgart	Bitburg	Berlin
Jan	10.4	7.8	7.7	11.5	7.7	39	42	54	75	39
Feb	8.3	7.4	6.8	7.4	8.5	48	33	33	45	60
Mar	8.1	7.5	6.4	6.4	6.2	33	57	33	33	24
Apr	7.0	6.6	5.8	3.8	5.4	45	21	15	9	15
May	6.4	7.7	3.6	3.6	5.1	24	57	6	6	12
Jun	4.2	9.2	3.5	3.3	4.0	12	48	9	6	9
Jul	4.6	5.7	6.0	3.2	3.0	18	12	15	6	3
Aug	4.7	4.7	3.9	4.2	3.6	21	21	6	9	6
Sep	6.0	5.4	4.6	4.7	5.3	33	18	12	12	12
Oct	8.7	6.8	5.7	6.7	7.0	36	21	18	33	36
Nov	9.7	8.4	8.6	9.9	8.8	51	84	63	63	51
Dec	10.5	8.3	11.2	11.8	9.0	42	114	45	75	48
Total	8.4	7.5	7.1	8.6	7.8	51	114	63	75	60

TABLE 3b. DURATION OF TYPE I WEATHER (HOURS), 1949–1970

Month	50 Percent					90 Percent					Number of Individual Cases				
	Hannover	Hof	Stuttgart	Bitburg	Berlin	Hannover	Hof	Stuttgart	Bitburg	Berlin	Hannover	Hof	Stuttgart	Bitburg	Berlin
Jan	8.3	5.4	5.0	7.5	5.6	23.3	16.6	16.1	26.4	16.1	145	187	89	154	116
Feb	6.2	5.9	4.9	5.1	5.5	15.4	14.7	13.9	15.6	18.6	127	141	63	112	86
Mar	6.7	4.6	4.0	4.3	4.7	16.0	16.2	14.3	13.8	12.4	118	129	33	49	55
Apr	4.7	5.3	4.9	3.4	4.5	14.3	13.6	10.3	6.0	9.8	85	66	29	25	27
May	4.8	4.5	3.2	3.3	4.5	12.7	17.3	4.9	5.2	9.2	62	38	19	15	10
Jun	3.6	5.9	2.9	3.0	3.4	7.1	20.6	5.3	4.4	7.0	36	27	13	21	6
Jul	3.7	5.2	4.9	2.9	3.0	7.8	10.2	12.4	4.0	3.0	44	18	5	16	6
Aug	3.6	3.4	3.7	3.7	3.2	8.3	9.0	5.8	6.8	5.1	50	33	16	38	11
Sep	4.4	4.4	4.1	4.0	4.7	10.7	9.9	7.5	8.1	9.8	64	55	62	47	22
Oct	6.8	5.6	5.0	5.1	5.1	17.1	13.9	10.5	13.4	14.3	144	113	150	141	100
Nov	6.9	4.8	5.0	5.9	6.0	21.1	18.1	19.4	23.6	19.3	174	149	99	146	153
Dec	8.2	4.6	8.7	8.0	6.7	22.7	17.4	25.0	27.9	19.0	164	207	96	192	152
Total	6.0	4.6	4.5	5.1	5.3	17.8	14.7	14.9	19.8	16.4	1213	1163	674	956	744

An added feature of the three hourly duration study is a survey of begin and end of type I weather as exhibited in Table 4. All 12 stations were summarized comprising an areal average, and the begin and end was counted in three hourly steps. As anticipated most cases start between 3 and 6^h (GMT) with a switch from 03^h to 06^h for summer and winter months, respectively. This type of diurnal cycle can largely be attributed to the diurnal temperature cycle, where cooling in the morning hours leads to fog and ceiling. The begin at the noon hours cannot be readily explained although these cases comprise mostly situations when type I weather may be due to frontal passage.

The lower part of Table 4 contains the count when type I weather ends. A distinct peak exists at 09^h (GMT). Again, a shift between 06 and 09 hour from summer to winter can be observed in accordance with the daily cycle.

It should be noticed that a division by 12 provides the average number per station for the 22-year period, and the second division by 22 furnishes the average number of cases by month per station. The total number of cases remain the same for the tabulations of begin and end, as an event of type I weather was counted in the month where the midpoint of the total length occurred. Hence, the repetition of the sums and averages for the lower part is not necessary.

As we learn from inspection of Table 4, the average of type I weather over the Central European region ranges between five and six cases in the months October through January and is very low in summer. One may consider this a contradiction to the results deducted in a previous report on areal probability [1], as the chances of type I weather would appear to be around 20 percent.

It must be stressed, however, that this interpretation is not correct. The result here must be compared with the single station occurrence, which is considerably higher. When the requirement of simultaneous occurrence of several stations is introduced, the probability drops considerably. It should be repeated that the areal probability for six stations with type I weather in winter was only 5 percent while a relaxation to four out of six stations increased this probability to 22 percent. It is, therefore, of vital importance to formulate the exact conditions to be pertinent for evaluation of the chances.

4. Duration by Days

Since the data were available at three hourly intervals, the study of the duration by hours length was relatively easy since the only decision was the treatment of cases when no type I weather appeared.

TABLE 4. BEGIN AND END OF TYPE I WEATHER (HOURS, 12 STATION SUMMARY), 1949–1970

Begin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
00^h	179	153	94	70	57	45	38	66	126	306	195	217	1546
03	155	154	150	118	101	79	75	130	247	326	230	192	1955
06	270	230	188	100	42	44	32	79	183	389	282	305	2144
09	152	124	31	14	18	14	10	8	15	35	120	191	732
12	99	45	27	8	11	5	3	4	5	24	63	104	398
15	109	63	31	21	7	7	7	6	15	27	99	156	548
18	176	111	68	34	11	13	9	14	24	25	150	177	872
21	172	134	67	45	23	21	8	20	45	216	230	177	1158
Total	1312	1014	656	410	270	228	182	327	660	1406	1369	1519	9353
12	109	84	55	34	24	19	15	27	55	117	114	127	Average per station
22	5.0	3.8	2.5	1.5	2.1	0.9	0.7	1.4	2.5	5.3	5.2	5.8	Average per station
End	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
00^h	161	100	66	36	19	16	11	13	27	85	148	188	870
03	131	89	43	34	21	26	13	21	37	93	130	158	796
06	161	125	132	110	122	87	88	154	213	281	206	190	1869
09	283	275	256	150	56	55	44	112	298	660	386	298	2873
12	183	205	70	38	29	18	13	11	46	184	180	213	1190
15	141	90	33	8	12	4	2	7	12	39	99	160	607
18	118	61	31	15	6	10	5	2	15	37	96	148	544
21	134	69	25	19	5	12	6	7	12	27	124	164	604

The definition of a day with type I weather is rendered more difficult. The day has 24 hours, and in the strict sense of the definition, consecutive days should apply when the duration exceeds 24 hours. This would defeat the purpose of the evaluation of the prediction probability, since it is known that a strong diurnal cycle exists, and that we may find consecutive days with adverse weather in the morning hours, although on both days it may last only a fraction of the day, e.g., less than 6 hours. These cases should, therefore, appear as 2 days with type I weather.

In turn, eliminating a day with only 1 hour showing type I weather may later influence the study of simultaneous occurrence of adverse weather over extended areas. It was, therefore, decided to count a day with type I weather when one of the three hourly records fell into the type I category. This simplified the program writing for computer processing.

This determination of a day with type I weather leaves one point unsatisfied, however. When type I weather starts at 9 p.m. and continues into the next day, these days are counted as 2 consecutive days, which does not seem appropriate when compared with 2 consecutive days with adverse weather in the morning on each of the 2 days. A sophisticated scheme was first considered, but a simple shift of the begin of the day to 18^h appeared to overcome most of the difficulty. The division at 12^h noon lends itself as another choice if the begin of type I weather were only taken into account (Table 4). After consideration of the end of type I weather, however, the 18^h was decided. Otherwise, cases lasting into the afternoon would be counted as 2 days. The best choice may have been the afternoon hour of 3 p.m. As can be seen, however, from the subsequent results, the division of the day into an interval 00 through 21 hour (inclusive) and the counting of the new day from 18 hour through 15 hour of the next day played an insignificant role in the outcome of the duration of days with type I weather. It was, therefore, decided not to calculate an additional set of tables with the division of the day at 15 hour.

The results of the calculations of runs are listed in Tables 5a and b and 6a and b with the same characteristics as for the hourly duration. A first glance at the maximum number of consecutive days with type I weather as given in Tables 5a and 6a reveals that the maximum run is higher for four out of the five stations in the division of the day at 18 hour. This may be puzzling in the first moment, as one would have expected, that too many days have been counted in the midnight division. An explanation must be sought in the following.

As the records show, the maximum of 17 days occurs from 6 to 22 December 1963, while the 20 days (with 18^h division) appear from 29 November to 18 December 1969. Obviously some adverse weather in the

TABLE 5a. DURATION OF TYPE I WEATHER (IN DAYS, FROM MIDNIGHT TO MIDNIGHT), 1949–1970

Month	Mean					Maximum				
	Hannover	Hof	Stuttgart	Bitburg	Berlin	Hannover	Hof	Stuttgart	Bitburg	Berlin
Jan	2.9	3.6	2.4	3.0	2.3	9	13	7	13	8
Feb	2.9	2.9	1.8	2.5	2.3	8	12	5	7	6
Mar	2.2	3.0	1.6	1.8	1.8	9	9	4	5	6
Apr	2.1	2.6	1.8	1.5	2.1	5	8	5	4	8
May	1.9	1.9	1.4	1.5	1.8	5	4	3	3	4
Jun	2.1	2.1	1.4	1.7	1.6	6	6	2	4	2
Jul	1.8	1.9	2.2	1.4	2.0	4	4	5	3	3
Aug	1.6	2.0	1.5	1.8	1.6	4	4	3	4	3
Sep	2.0	2.3	2.1	1.8	1.8	6	7	7	4	4
Oct	3.1	3.2	2.3	2.7	2.4	12	15	11	11	9
Nov	2.9	3.2	1.9	2.6	2.8	10	14	6	9	10
Dec	3.0	3.7	2.4	3.0	2.4	17	13	7	10	9
Total	2.5	2.9	2.0	2.4	2.3	17	15	11	13	10

TABLE 5b. DURATION OF TYPE I WEATHER (IN DAYS, FROM MIDNIGHT TO MIDNIGHT), 1949-1970

Month	50 Percent					90 Percent					No. of Cases N				
	Hannover	Hof	Stuttgart	Bitburg	Berlin	Hannover	Hof	Stuttgart	Bitburg	Berlin	Hannover	Hof	Stuttgart	Bitburg	Berlin
Jan	2.5	3.1	2.1	2.4	1.8	5.4	7.1	4.2	5.8	4.2	83	73	61	78	76
Feb	2.6	2.3	1.6	2.2	2.0	5.4	5.6	3.2	4.6	4.2	71	67	52	65	55
Mar	1.7	2.5	1.5	1.6	1.5	4.2	6.1	2.6	3.0	3.0	73	61	35	44	43
Apr	1.9	2.2	1.5	1.3	1.6	3.6	4.4	3.1	2.6	3.9	64	47	27	23	24
May	1.6	1.8	1.3	1.4	1.6	3.3	3.4	2.3	2.3	2.9	52	31	23	18	15
Jun	1.8	1.8	1.3	1.5	1.6	3.8	3.6	2.0	2.8	2.2	38	26	14	23	14
Jul	1.6	1.8	2.0	1.3	2.0	3.1	3.0	3.8	2.2	3.0	43	20	9	22	11
Aug	1.4	1.9	1.4	1.6	1.5	2.7	3.4	2.5	3.1	2.5	45	32	19	38	20
Sep	1.7	2.0	1.8	1.6	1.6	3.6	4.0	3.9	3.1	2.9	59	45	54	44	20
Oct	2.5	2.3	1.7	2.2	1.9	6.0	6.7	4.3	5.0	4.6	72	63	89	82	61
Nov	2.3	2.4	1.5	2.2	2.4	5.6	6.5	3.4	5.0	5.4	90	72	77	83	84
Dec	2.1	3.0	2.1	2.4	1.9	5.7	7.7	4.3	6.0	4.7	90	79	68	100	95
Total	1.9	2.2	1.6	1.9	1.8	4.7	5.9	3.7	4.7	4.3	780	616	528	620	518

TABLE 6a. DURATION OF TYPE I WEATHER (IN DAYS, FROM 18^h TO 18^h), 1949–1970

Month	Mean					Maximum				
	Hannover	Hof	Stuttgart	Bitburg	Berlin	Hannover	Hof	Stuttgart	Bitburg	Berlin
Jan	2.9	3.5	2.0	3.3	2.2	10	17	7	18	8
Feb	2.9	2.9	1.9	2.4	2.3	8	12	5	7	6
Mar	2.1	3.2	1.8	1.7	1.8	9	11	4	5	6
Apr	2.2	2.3	1.6	1.5	2.0	9	7	3	4	4
May	1.9	2.2	1.4	1.4	1.6	5	8	3	3	2
Jun	1.9	1.9	1.4	1.7	1.6	6	5	2	4	3
Jul	1.8	2.0	1.9	1.4	1.9	5	4	3	3	3
Aug	1.7	2.0	1.5	1.6	1.7	5	4	3	4	3
Sep	1.8	2.2	2.1	1.8	1.7	5	7	7	4	3
Oct	2.7	2.7	2.3	2.6	2.1	12	11	11	11	9
Nov	2.6	2.9	1.9	2.7	2.4	11	11	6	11	8
Dec	2.9	4.1	2.3	3.1	2.6	20	17	7	11	11
Total	2.4	2.9	2.0	2.4	2.2	20	17	11	18	11

TABLE 6b. DURATION OF TYPE I WEATHER (IN DAYS, FROM 18^h TO 18^h), 1949–1970

Month	50 Percent					90 Percent					No. of cases N				
	Hannover	Hof	Stuttgart	Bitburg	Berlin	Hannover	Hof	Stuttgart	Bitburg	Berlin	Hannover	Hof	Stuttgart	Bitburg	Berlin
Jan	2.5	2.6	1.6	2.4	1.8	5.5	7.0	3.7	6.6	4.1	84	78	65	73	77
Feb	2.5	2.3	1.6	2.1	2.1	5.3	5.4	3.3	4.5	4.1	69	66	52	67	55
Mar	1.7	2.7	1.6	1.5	1.5	3.9	6.7	2.9	2.8	3.1	72	59	34	44	45
Apr	1.7	2.0	1.4	1.3	1.8	4.1	3.9	2.6	2.5	3.4	64	46	27	24	25
May	1.7	1.7	1.3	1.3	1.7	3.2	3.9	2.3	2.3	2.2	51	33	24	18	16
Jun	1.6	1.7	1.4	1.5	1.6	3.3	3.2	2.1	2.9	2.6	39	25	14	22	14
Jul	1.6	1.9	1.9	1.3	1.9	3.3	3.0	2.6	2.2	2.7	43	21	9	21	13
Aug	1.4	1.9	1.3	1.4	1.6	2.9	3.5	2.4	2.8	2.5	43	30	19	38	20
Sep	1.5	1.8	1.7	1.6	1.7	3.2	3.9	3.9	3.1	2.6	61	48	54	42	19
Oct	2.1	2.1	1.7	2.1	1.6	5.3	5.5	4.3	4.9	4.3	73	67	88	83	63
Nov	2.0	2.4	1.5	2.1	2.1	5.1	5.6	3.6	5.2	4.6	96	73	78	85	91
Dec	1.9	3.1	2.0	2.1	2.0	5.6	8.6	4.0	6.3	5.1	92	79	71	95	90
Total	1.8	2.1	1.6	1.8	1.7	4.5	5.8	3.6	4.7	4.1	787	625	535	612	528

evening hours adds now a day with adverse weather within the period from 29 November to 18 December, linking together two previously separate periods in the 18-hour division, where formerly a period of 24 hours free of adverse weather had existed. These changes are completely within the range of random fluctuations in statistical analysis and should not be over rated.

The averages as contained in Tables 5a and 6a compare favorably between the two choices of divisions of the day. No significant differences can be noticed. We deduct from the tables that adverse weather in the winter months lasts in the average between 2 and 4 days.

Again a more appropriate characteristic is the median as given in Tables 5b and 6b. These tables display that adverse weather appears in winter on 2 to 3 consecutive days in 50 percent of the cases, which is again slightly less than the average. Five to seven consecutive days at the individual station are encountered in 10 percent of the time. These are definitely periods where proper prediction would be possible.

The last columns in Tables 5b and 6b contain the number of cases. Since the record period comprises 22 years division by 22 would render the average number of runs with type I weather. In January we would derive 3.8 cases for Hannover. When multiplied by the average duration we obtain 11 days; i.e., type I weather would be present on 11 days although with various individual length. This is quite a high occurrence. Even if we substitute the median for the mean we reduce the number of total days with type I weather only to about 10 days.

Had we defined a day of type I weather by the selection of a specified hour, e.g., 06 GMT, the average length of the days with adverse weather would be less. Thus the high number of days with type I weather in the winter months is not contradictory to previous results. We may even refer to Table 4, where five cases of type I weather would be expected in the average per station in January. The 3.8 cases are actually below this figure and indicate multiple begins (and ends) within 1 day.

It should be further emphasized that the established chances and duration length are strictly valid for the single station consideration. Simultaneous presence of type I weather at several stations reduces duration in days considerably. In fact, various six-station combinations were studied and the highest number of cases with simultaneous type I weather was 47 for the entire 1960—1970 period with the longest period of 5 days. This amounts to one case per winter month. It is evident that this requirement of six stations falling into the category of type I weather depicts only the worst and extreme situations of adverse weather with largest areal extent.

5. Duration of Widespread Adverse Weather

It was pointed out that it is difficult to obtain reliable figures on the duration of adverse weather over an extended area. Correct chances can only be computed by a sophisticated model either from area cloud cover or ceiling maps or by designing a complicated computer program by which the simultaneous occurrence with random fluctuations in the adjacent classes is included. To keep the computer analysis simple and inexpensive, eight six-station combinations similar to the system for spatial distribution in an earlier report have been employed. The eight six-station combinations are listed in Table 7 (see Figure A-8 of the Appendix). They are not completely ideal but had been depicted for widespread area coverage under certain conditions. When four out of six stations displayed type I weather, the day was counted. The results have been compiled in Table 8.

TABLE 7. SIX-STATION COMBINATIONS (1960-1970)

(1)	Hannover, Hof, Grafenwoehr Hahn, Sembach, Bitburg
(2)	Hannover, Hof, Grafenwoehr Frankfurt, Heidelberg, Stuttgart
(3)	Fulda, Hof, Grafenwoehr Hahn, Sembach, Bitburg
(4)	Fulda, Hof, Grafenwoehr Frankfurt, Heidelberg, Stuttgart
(5)	Berlin, Hof, Grafenwoehr Hahn, Sembach, Bitburg.
(6)	Berlin, Hof, Grafenwoehr Frankfurt, Heidelberg, Stuttgart
(7)	Hahn, Fulda, Hof Bitburg, Frankfurt, Stuttgart
(8)	Berlin, Fulda, Hof Bitburg, Frankfurt, Stuttgart

We learn from Table 8 immediately that the division by 00 or 18 hour for the definition of a day with adverse weather is insignificant. Seemingly the only difference is a small tendency towards a peak of situations with 2 days duration in the 18^h division. The frequency numbers are in most cases too close, however, to draw decisive conclusions.

TABLE 8. AVERAGE DURATION OF SIX-STATION COMBINATIONS (1960-1970)

	Total	Days						
		1	2	3	4	5	> 5	
00-Hour Division of Day								
Dec-Feb	36	14	13	5	2	1	1	
Oct-Apr	74	30	26	10	4	2	2	
May-Sep	7	3	4	0	0	0	0	
Year	81	33	30	10	4	2	2	
Max	113	35	43	22	7	2	4	No. 1
Min	59	27	20	8	2	2	0	No. 8
18-Hour Division of Day								
Dec-Feb	37	12	15	6	2	1	1	
Oct-Apr	75	26	30	11	4	2	2	
May-Sep	7	2	4	0	1	0	0	
Year	82	28	34	11	5	2	2	
Max	114	34	48	20	7	2	3	No. 1
Min	58	18	28	8	2	1	1	No. 6

Six different frequency distributions have been selected for display in Table 8. The winter months December—February, the summer period May—September, and the time from October through April disclose the seasonal variation of occurrence. This variation is in agreement with the expectation and results presented in the single station analysis.

The average of the year, the station combination with the maximum number of type I weather, and the configuration with the minimum cases of type I weather are given in the lower part of the respective section. Although apparently the combination No. 6 emerges with the minimum number of cases for the 18-hour division while the six stations of No. 8 constitute the minimum for the 00-hour division; both station groups are practically equivalent. Combination No. 8 has 61 cases in the 18-hour division and combination No. 6 has 61 cases in the 00-hour division. The differences are not statistically significant, and either combination could have been exchanged for the minimum.

The average number of cases with 75 (74) in the months October through April would indicate only six to seven cases per winter season or roughly one case per month. This is considerably less than for the single-station analysis. It is by far less than the number of individual dates for the station with type I weather at the individual six-station combinations. As described in Section III.2, a total number of 204 large scale patterns evolved for the same period of record. It must, therefore, be concluded that the grouping of stations influences considerably the duration analysis. While type I weather is widespread (four out of six) for one group, it is not simultaneously occurring at all eight combinations. The results of Table 8 can, therefore, only be conclusive with respect to the average durations of between 1 and 2 days, which would be in accord with the single-station analysis. We further may deduct that about 25 percent of the cases last longer than 2 days.

A further investigation of the duration for smaller areas such as regional subsections was found appropriate. Combinations of four and five stations were prepared as listed in Table 9. The first summary comprises the Northern part of Germany, while the second combination can be classified as the West. Two other grid nets with five stations were selected next, with an exchange of one station, i.e., Frankfurt for Stuttgart. As later discussed (Table 10), the substitution had little effect, which proves that no significant changes will result when stations from equivalent climatic regimes are exchanged or substituted.

TABLE 9. FOUR- AND FIVE-STATION COMBINATIONS

(1)	Berlin, Hannover, Hof, Frankfurt (North)	1954-1970
(2)	Bitburg, Sembach, Frankfurt, Stuttgart (West)	1954-1970
(3)	Bitburg, Stuttgart, Hof, Berlin, Hannover (Total 1)	1954-1970
(4)	Bitburg, Frankfurt, Hof, Berlin, Hannover (Total 2)	1954-1970
(5)	Fuerstenfeldbruck, Stuttgart, Frankfurt, Hof (South)	1949-1957

TABLE 10. DURATION OF FOUR- AND FIVE-STATION COMBINATIONS
(DAY DEFINED FROM 18^h to 18^h OF THE NEXT DAY, TABLE 8 CONVERTED TO LENGTH OF TIME PERIOD 1954-1970)

	Total	Days 1	2	3	4	5	> 5
December—February							
North	56	26	19	8	2	0	1
West	90	47	23	12	5	2	1
Total 1	80	29	24	15	6	3	3
Total 2	83	30	30	12	4	2	5
South	24	10	9	2	2	0	1
Table 8	57	19	23	9	3	2	1
October—April							
North	106	47	39	14	4	1	1
West	160	80	43	20	11	4	2
Total 1	145	51	53	24	10	4	3
Total 2	147	51	62	21	5	3	7
South	37	16	15	3	2	0	1
Table 8	115	40	46	17	6	3	3
May—September							
North	4	1	2	1			
West	18	12	6				
Total 1	12	3	8	1			
Total 2	8	2	4	2			
South	2	2					
Table 8	11	3	6	1	1		
Year							
North	110	48	41	15	4	1	1
West	178	92	49	20	11	4	2
Total 1	160	54	61	25	10	4	6
Total 2	157	53	66	23	5	3	7
South	39	18	15	3	2	0	1
Max. No. 1 (Table 8)	177	53	74	31	11	3	5

While the four- and five-station combination is based on the 17 years (1954–1970) as a homogeneous period when simultaneous observations are available at all stations, the last regional summary, the South, comes from the 9 years (1945–1957). The outcome of the durations with days (from 18 hours to 18 hours) of adverse weather at three or more stations is exhibited in Table 10 for the winter season (December–February), the 7 months October through April, and the remaining months May through September. A synopsis of the total year completes the sections of Table 10.

We compare first the outcome of the yearly total for Tables 8 and 10. It is evident that the amount of cases should be higher in Table 10 than in Table 8 since the summary is for a 17-year period against 11 years, respectively. When the ratio 11:17 is applied, we calculate for the maximum count $(114{:}11) \times 17 = 177$, a number close to the 178 of the West combination. We discover, therefore, a correspondence between the six-station combination (1) of Table 7 and the West of Table 9. Although the six-station study covers a larger area, it centers on three western stations (Hahn, Sembach, Bitburg) which may account for the resemblance. The other part of the frequency distribution of duration of type I weather was converted for this combination and is listed on the last line of Table 10.

It is striking that the number of 1-day durations is almost twice as high for the West compared with the result from the six-station combination as given in Table 8. One may attribute this to the smaller area coverage for the four stations, namely, the Western part only. Obviously adverse weather of 1-day duration appears more often when the area of consideration is small. There is a higher chance of simultaneous occurrence over a smaller area. This fact is confirmed by the comparison between West, total 1 and total 2, and can be observed in the seasonal summaries, too. It must be added, however, that regional differences are quite apparent, such as between West and North, although the square miles covered by the four stations from the North is larger than for the West. This tends to decrease the duration cases.

Since the five-station combination is based on adding one station to the North grid net, the relaxation of the condition to require adverse weather at three out of five stations renders almost 50 percent more cases, mostly in the form of longer durations.

The seasonal tabulations of Table 10 go parallel with the presented results of the annual summary, and further details may be left to the study by the reader. It has become quite evident, however, that the duration of adverse weather over a wide area depends on regional differences, and to some extent on station selection, where inhomogeneous climatic regions are combined. An additional factor is the requirement, i.e., what is considered adverse weather over an area. Therefore, an attempt will be made to investigate adverse weather conditions over Central Europe from a slightly different angle for prediction purpose.

Section III. PREDICTABILITY ASPECTS OF ADVERSE WEATHER

It is common knowledge that predictability of meteorological phenomena depend on the scale of time and space of the forecast. The success of a forecast decreases with increasing time distance of the event from the point of prediction. In addition, events with a short duration compared with the forecast interval are in general more difficult to assess correctly than weather conditions lasting over a longer period of time. Thus, for a 1-day forecast it is more difficult to pin a frontal rain of 1-hour duration to the exact time of occurrence than to predict rain for a system whose precipitation time lasts 24 hours. Persistance of an element over a longer time period enhances the chances for prediction success. The previously established results on the duration of adverse weather become, therefore, an integral part of the evaluation.

A second factor is the predictability in the areal scale. As pointed out by Lorenz [3], nonlinearity of the guiding equations of the physical behaviour of meteorological elements gives rise to small-scale motion and nonperiodicity. This limits the range of an accurate detailed local forecast, whose probability of success is presently assumed to vary between 85 and 90 percent and may not considerably improve in the next decade.

In contrast, the prediction of large-scale patterns has a higher chance of success. As Lorenz [4] has recently demonstrated, the states of the atmosphere up to 12 days display nonrandom patterns. Then large scale patterns or phenomena over a widespread area should be predictable. In fact for many of the 1-day predictions of large-scale pressure patterns the chances are assumed to be between 90 to 95 percent and could even slightly improve in the next decade.

The difference between local and areal scale may be demonstrated by the following example. Let us assume we have a 10-percent probability for the occurrence of a certain meteorological phenomena, e.g., a thunderstorm. For the moment we may neglect the fact that an event of 10-percent probability may not occur in 10 trials. We postulate that it takes place.

The areal probability of 10 percent would then be interpreted that a thunderstorm would be observed at 1 out of 10 stations. The event takes place within a certain time interval; only the station is not known and left to random play.

The problem becomes quite different for the local forecaster. One has to predict when the storm will occur at a particular station. It is known that in 10 similar situations the storm will be observed once at this particular station of interest, provided areal chances are alike for all 10 stations.

Under the present assumptions, the areal forecast should be a success every time, while the local forecaster may decide to predict no thunderstorm as the most likely choice, and would be wrong in one case; i.e., his score is only 90 percent. The local forecaster has the more difficult task.

It is evident that the difference between areal and local forecast was evaluated under simplified conditions which may not exist in practice, and a much more sophisticated model is necessary. The basic fact remains, however, that the local forecaster must predict the occurrence for the individual trial, which is a more difficult task, and small-scale motion may prevent the same high score of success [4].

We further learn from the illustrated example that a correct assessment of the skill score of a forecaster can in principle not be given without the knowledge of the background of the prediction model or the tool by which the forecast is derived. Thus all presented chances given later in this section are speculative evaluation.

The chances are calculated, however, under the assumption that a forecaster would have certain tools available based on general knowledge which is derivable. One factor is demonstrated later; i.e., the connection of type I weather with certain facets of the large-scale weather patterns. Before discussion of the forecasting chances continues, a short digression into the large-scale weather patterns in Europe (also called Grosswetterlagen = GWL) may be appropriate.

1. The Large-Scale Weather Pattern

These patterns were first introduced by Baur, Hess, and Nagel [5] and have been revised and redefined by Hess and Brezowsky [6]. The latter publication is a catalogue of the type for every individual day from 1890—1950. The period of record is being supplemented by a publication of the German Weather Service [7] up to the present date.

The system contains 19 types and one class of ambiguous or undetermined situations. Some of the types are subdivided into cyclonic and anticyclonic influence over Central Europe. A detailed description of the types has been given by Baur [8]. Examples of principle situations with type I weather have been depicted and are shown in the Appendix.

For the purpose of this study, a combination of the types has been utilized as developed by Bürger [9]. This combination concentrates on the major air flow (at the surface) over Central Europe. This leaves 11 types which then have been further combined into two groups (Tables 11 and 12). In principle the first group comprises types where type I weather occurs on the first day and fades out. These are types where

TABLE 11. FREQUENCY OF ADVERSE WEATHER (TYPE I) BY GWL-TYPE

	Group	Annual Summary, 1960—1970, 06 Hour						
		Day						
		1	2	3	4	5	6	7
W	1	23	11	7	4	2	4	0
H	2	21	22	25	27	12	6	6
SW	1	14	12	9	5	1	0	1
NW	1	4	3	2	1	1	1	
N	1	26	15	12	5	2	2	
L	2	2	4	4	3	1		
S	2	18	19	15	7	6	2	2
SE	2	5	7	3	2	1	0	1
E	2	14	15	13	12	6	5	3
NE	2	4	7	4	2			
Ww	1	3	1	1				
U	1	12	3	1				
Percentages of GWL								
W	1	13.1	6.3	4.5	3.7	2.9		
H	2	13.3	14.3	21.6	40.6	36.4		
SW	1	16.5	14.5	13.8	13.9	5.3		
NW	1	6.1	4.6	3.9	3.3	4.8		
N	1	17.0	10.1	10.0	6.7	4.3		
L	2	8.7	17.4	23.6	30.0	12.5		
S	2	12.9	13.7	14.1	12.9	18.8		
SE	2	20.0	28.0	14.3	14.3	14.3		
E	2	15.9	17.0	17.6	24.0	27.3		
NE	2	12.9	23.3	16.4	16.7			
Ww	1	13.1	4.4	6.2				
U	1	9.8	25.0					

adverse weather is largely caused by frontal passage (Table 12). Figure A-1 of the Appendix displays an example of northerly flow.

The second group displays the development of type I weather 3 to 4 days after existence of the GWL. The type I weather is largely caused by stagnant air over Central Europe such as in the given example of high pressure (Figure A-4 of the Appendix). More details on GWL and association with type I weather are given subsequently.

The large-scale weather patterns (Grosswetterlagen = GWL) were coded and placed on magnetic tape for computer application by E. Wahl,[1] who has made the tape available from 1890 to 1963 for this study. The period 1964—1970 was supplemented at the initiation of the author.

Table 12 lists the two principle groups. The data supporting the separation can be found in Table 11.

A frequency distribution of the occurrence of adverse weather over an extended area (as defined in detail in Section III.3) was established by GWL type. As can be concluded from Table 11, the large-scale patterns fall obviously into two groups. The first comprises the cases where the adverse weather displays a maximum (underlined) on the first day and the number of cases with type I weather on subsequent days decreases. As it is disclosed by Table 12, this first group embodies situations with Southwesterly to Northerly flow over Central Europe.

The second group comprises the Northeasterly to Southerly flow plus specialized situations with high or low pressure over Central Europe. For these GWL types, the adverse weather peaks on the second or a later day during the existence of the GWL type. This result may be subject to criticism since the GWL type lasts in the average about 3 to 4 days, and the peak of adverse weather may parallel the frequency of occurrence. The cumulative frequency distribution of the duration of GWL was, therefore, calculated for the individual types, and the percentage frequency of adverse weather with reference to this cumulative frequency was obtained. This gives the relative count of days with adverse weather for all cases of the GWL lasting the specified number of days or longer; e.g., 175 cases of GWL-type W lasted 1 or more days, etc. The relative frequency is, therefore, 23/175 = 13.1 percent, etc. The same grouping emerged as in the previous method except for U and the appearance of type I weather is, therefore, not a strict parallelism to the duration of GWL types.

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[1]Dr. E. Wahl, Department of Meteorology, University of Wisconsin, is a consultant to Physical Sciences Directorate.

TABLE 12. TWO GROUPS OF GROSSWETTERLAGEN (GWL, LARGE-SCALE WEATHER PATTERN) AS UTILIZED IN THE STUDY

Group I
W = West (Wa, Ws, Wz)
N = North (Na, HNa, HB, Nz, NHz, TrM
SW = Southwest (SWa, SWz)
NW = Northwest (NWa, NWz)
Ww = West with angular flow towards North
U = Undetermined
Group II
H = High over Central Europe (HM, BM)
S = South (Sa, Sz, TB, TrW)
E = East (HFa, HNFa, HFz, HFNz)
NE = Northeast
SE = Southeast (SEa, SEz)
L = Low pressure over Central Europe (TM)

It was decided to place U into group I largely due to its predominance of the absolute count of adverse weather on the first day and the generally short duration of U (only one case lasted 3 days for 1960–1970). Moreover, only a few situations exist where the GWL pattern cannot be determined for 2 consecutive days, and the significance of the relative amount of 25 percent cannot be assured. The empirical count could be caused by random play. The decision does not essentially influence the outcome of the prediction study since the first part is evaluating the second group only, and the combination of the two groups for the second part makes the assignment irrelevant.

The two groups as listed in Table 11 will be employed in the subsequent sections.

2. Adverse Weather by Large-Scale Pattern, Six-Station Model

It was stated earlier that the precise prediction tool of the forecaster in the 1980–1985 time frame is not known. It can be assumed, however, that weather maps as prepared today with the system of numerical analysis by computer methods would be available for 1 to 2 days forecast, maybe even on an improved basis. Further, a set of prediction maps up to 5 to 10 days with the quality of today's 48 to 72 hours outlook would probably exist. It is, therefore, postulated that the GWL would be known for at least up to 5 days. Thus the association with widespread type I weather can be employed as an evaluation basis.

The first model was constructed for the days when five to six stations of the six-station combinations utilized in the previous study of adverse weather (Tables 7, 8, 9, and 10 and Reference [1]) observed type I weather. These dates were listed, the GWL determined, and the day found when the adverse weather occurred with reference to the begin of the GWL. The result is exhibited in Table 13, sorted by the two groups of GWL.

TABLE 13. TYPE I WEATHER BY GWL, SIX-STATION MODEL (1960–1970, SEPTEMBER–APRIL)

GWL	Total Type I	Days After Begin						Total GWL	Individual Systems
		1	2	3	4	5	≥ 6		
W	22	12	5	2	0	2	1	92	16
N	22	7	5	3	3	3	1	101	20
SW	23	5	11	6	1			55	17
NW	-							33	-
WW	1						1	6	1
U	5	5						55	5
E	73	29	21	11	4	5	3	342	59
H	65	7	14	18	13	6	7	83	37
S	36	8	13	8	3	0	4	73	26
E	17	4	4	5	2	0	2	38	13
NE	3	0	2	1				12	3
SE	8	3	0	1	1	1	2	20	6
L	2	1	0	1				14	1
Σ	131	23	33	34	19	7	15	240	86

It becomes evident that for the first group, adverse weather decreases rapidly with increasing days of existence of the GWL, while the second group displays a maximum on the second to third day. The prediction chances for the second group only are further pursued as of interest.

We postulate first that the forecaster is able to identify systems with type I weather. The frequency of the GWL for the period 1960—1970, September—April, is listed in the next to last column of Table 13 and the number of individual GWL with adverse weather is given in the last column. One can immediately conclude that more than twice as many systems display adverse weather than for group I. While in the first group adverse weather appears for most of the GWL patterns only once, at least 50 percent show more than 1 day of occurrence of type I weather for the second group. (The total number of type I cases is contained in the first column of Table 13.)

Under the assumption that the forecaster would be able to identify the systems where later type I weather arises, the number of GWL systems with a certain number of days or more under existence are listed in the first row of Table 14. The cases with adverse weather are given in the second row. The relative number of the systems displaying adverse weather has been calculated as provided in row three, and the deviation from the average is exhibited in the fourth line.

We treat first a 1-day forecast, made on the first, second, etc., day of the GWL. We assume further that the forecaster has an average skill score of 85 percent when the average number of adverse weather appears. Then his skill score may be higher when the average number is above and lower when under the average. Under the regular 85-percent score, the success may be rated as shown in line 6 of Table 14.

It should be added that here the postulation does not specifically take into account any knowledge that adverse weather peaks at 2 to 3 days after existence of the GWL for this particular group. It was assumed that the forecast method reaches 85 percent when the average number of cases for adverse weather is fulfilled, and that the success is correlated with the empirical frequency of days with adverse weather on a particular day. A more sophisticated model would necessitate the availability of the precise forecasting tool for verification; e.g., present day predictability of GWL and adverse weather could be studied.

Next, the model is applied to long-range predictions. The regular postulated chances decreasing with time are given in the upper line of the medium range prediction section; i.e., for a prediction for the fourth day in advance the chances are assumed to be only 68 percent of

TABLE 14. PREDICTION CHANCES FOR MODEL TABLE 11 (EXPONENTIAL DECREASE OF DURATION FREQUENCY FOR GWL)

	Days Duration of GWL					
	1	2	3	4	5	≥ 6
N	240	191	153	120	94	80
Type I Weather	23	33	34	19	7	15
Percent	9.6	17.3	22.2	15.8	7.5	—
Deviation from average	-4.9	2.8	7.7	1.3	-7.0	—
	1-Day Prediction					
Regular	85	85	85	85	85	
With GWL	80	88	93	86	78	
	Medium Range Prediction					
Regular	85	80	75	68	60	
With GWL	80	83	83	69	53	

success, a conservative figure, which may be higher in the time frame 1980—1985. With the same principle of correlation between the success and the frequency of cases the score is presented in the last line of Table 14. The probability for the medium range prediction under this model is about the same for the first 3 days than today's average chances for a 1-day forecast.

Although the given probabilities of a successful forecast are speculative and should be considered as such, they may be realistic and achievable in the 1-day prediction case, and may be conservative for the medium range prediction. Further models follow.

3. The Eight- and Nine-Station Models

In the previous section only dates with adverse weather at six-station combinations have been selected, and no uniform attempt has been made to define systematically an adverse situation. The resulting dates of type I weather appeared in these six-station combinations when five out of six stations had observed type I weather. On a particular date, from one to all of the eight combinations could fulfill this requirement. These dates thus reflect a variable degree of areal extent, and a systematic approach was considered desirable.

First a station network was adopted from the 12 stations listed in Table 1. A homogeneous period of record for all stations was selected with 1960–1970; this eliminated Fuerstenfeldbruck. Grafenwoehr and Hahn were rejected to reduce the imbalanced weight of individual regions (see Figure A-8 of the Appendix). The remaining nine stations were studied in two divisions: without Berlin (eight stations only) and with Berlin (nine stations). The first part of the study treats the eight-station network; the nine-station model follows.

At first a survey was obtained on how many of the network stations display simultaneously adverse weather over Central Europe. Two methods were employed. In the first procedure a straight count of the number of stations was obtained. The second arrangement included the margin class types II and IIIA (Figure 1), but only with the weight 1/2. No. 4 in the first method means therefore that four stations have simultaneously adverse weather. In the second case the No. 4 is a combination ranging from four single stations to eight stations, all in the margin classes, although this last case is very seldom. As expected, the frequency of cases in the two methods differ, but the procedure forms an objective basis for the selections of a threshold that could be considered an important case of widespread adverse weather over Central Europe.

The results of the station count for the period 1960–1970 are exhibited in Tables 15 and 16 for the eight- and nine-station combination. As disclosed, a definite daily trend (Table 15) and seasonal variation (Table 16) exists. This outcome confirms earlier findings of daily and seasonal cycles and was expected. We learn further that the threshold four at the morning hour 06 comprises about 10 percent of the cases when the margin classes are included and about 6 percent without margin classes. This basis was, therefore, selected for the eight-station model. The seasonal breakdown displays that the selection of four as a threshold would extract about 10 to 15 percent of the cases in winter and fall, which is a reasonable amount to be classified as widespread adverse weather in agreement with earlier findings. Table 17 exhibits the absolute amount of cases with threshold four or more and permits to evaluate the effect of adding the margin classes.

The nine-station model was based on the threshold five. It is obvious that the adoption of the threshold five limits the days with widespread adverse weather from the eight-station survey, but takes adequately into account the addition of Berlin. The absolute count for the threshold is again exhibited in Table 17. Incidentally, the threshold of five requires that at least one station has type I weather observed.

TABLE 15. SIMULTANEOUS OCCURRENCE OF ADVERSE WEATHER, DAILY TREND

Eight Station

	Hour	1	2	3	4	5	6	7	N
Type I plus margin	00	100	44.6	18.6	7.7	2.9	0.7%		1459
	06	100	58.2	32.8	16.8	8.4	2.9	0.5%	2343
	12	100	47.5	24.4	11.8	4.1	0.6%		1293
	18	100	45.1	19.9	8.8	3.1	0.9	0.1%	1145
Type I	00	100	36.6	13.4	6.0	2.3	0.7%		1199
	06	100	46.1	24.3	12.6	6.1	2.3	0.6%	1940
	12	100	37.5	15.2	5.7	1.6	0.5%		975
	18	100	34.9	12.6	5.0	1.9	0.8	0.1%	872

Nine Station

	Hour	1	2	3	4	5	6	7	8	N
Type I plus margin			48.2	25.3	10.0	4.2	1.8	0.2%		1563
			61.4	36.4	21.0	10.8	5.3	1.6	0.2%	2488
			49.9	27.5	14.9	6.1	1.8	0.3%		1406
			49.6	23.4	11.4	4.4	1.5	0.4	0.1%	1255
Type I		100	40.3	17.6	7.1	3.1	1.2	0.2%		1243
		100	50.5	27.1	14.8	7.9	3.7	1.2	0.3%	2015
		100	38.0	16.9	7.2	2.7	0.9	0.1%		1042
		100	38.1	14.9	6.0	2.7	1.1	0.2	0.1%	936

TABLE 16. SIMULTANEOUS OCCURRENCE OF ADVERSE WEATHER, SEASONAL VARIATION

Eight Station										
	Season	1	2	3	4	5	6	7	N	
Type I plus margin	Winter	100	63.7	37.2	18.5	9.3	3.1	0.3%	675	
	Spring	100	50.7	23.6	8.9	2.0	0.7%		542	
	Summer	100	43.0	18.7	8.1	2.8	0.7%		433	
	Fall	100	68.1	44.4	26.8	15.9	5.9	1.4%	693	
Type I	Winter	100	49.6	26.4	14.4	5.8	2.3	0.4	568	
	Spring	100	38.0	14.4	3.8	1.7	0.5		424	
	Summer	100	33.9	13.7	5.1	0.9	0.3		336	
	Fall	100	58.5	35.0	21.1	12.4	4.7	1.6	612	
Nine Station										
	Season	1	2	3	4	5	6	7	8	N
Type I plus margin	Winter	100	67.6	42.6	24.4	13.2	5.4	1.5	0.1%	725
	Spring	100	56.0	29.7	11.9	3.7	1.2	0.2%		573
	Summer	100	42.3	19.3	9.7	3.2	1.1%			466
	Fall	100	71.8	46.5	32.0	18.9	11.2	3.9	0.7%	724
Type I	Winter	100	54.0	22.2	16.9	8.3	3.7	1.0	0.2	591
	Spring	100	42.2	17.2	5.2	1.8	0.7			443
	Summer	100	34.5	14.7	6.0	1.1	0.3			348
	Fall	100	61.8	37.3	24.3	15.5	7.6	3.0	0.8	633

TABLE 17. ABSOLUTE VALUES OF SIMULTANEOUS OCCURRENCE OF ADVERSE WEATHER

	Hour	Station Eight ≥ 4	Station Nine ≥ 5	Season	Station Eight ≥ 4	Station Nine ≥ 5
Type I plus margin	00	113	66	Winter	125	96
	06	394	269	Spring	18	21
	12	153	86	Summer	35	15
	18	101	55	Fall	186	137
Type I	00	72	39	Winter	82	49
	06	244	159	Spring	16	8
	12	56	28	Summer	17	4
	18	44	25	Fall	129	98

After this objective definition of the term "widespread adverse weather" over Central Europe, we return to the prediction judgement. A day with adverse weather was counted when the above conditions were met under three time sections, at 06 hour, for a 24-hour day starting at midnight and one at 18^h. The latter division is published here, as the findings of the other divisions resemble the given models so closely that nothing new would be added. A breakdown by the individual GWL types was established. Two prediction models were analyzed. The details of the investigation are given in Tables 18, 19, 20, and 21. The first line (N) in the tables provides the count of the GWL systems in group II (Table 12). The form chosen here relates to the cumulative frequency; i.e., the GWL lasted the indicated number of days given by the heading, or longer. In the third row with n_A, the frequency of widespread adverse weather is listed for the individual day. For example, we learn from Table 18 that 253 systems lasted 2 or more days, and in 96 cases the adverse weather as defined above was observed on the second day. This provides about 38 percent of the cases; the calculated percentage is shown in the row n_A/N. Since the final count n_A in the column heading "6 days" includes all days with adverse weather on any day over six inclusive, it was decided to exclude this part from the prediction evaluation.

TABLE 18. EIGHT-STATION PREDICTION MODEL, SEPTEMBER–MARCH (1960-1970)

		Prediction No.	Days						Total	Average	Factor
			1	2	3	4	5	6			
Group II	N		258	253	192	123	68	41		—	
	N_A		171	170	134	92	55	36		—	
	n_A		85	96	75	52	24	21	353	-	
	n_A/N	1	32.9	37.9	39.1	42.3	35.3%	—	187.5	37.5	1/2
	n_A/N_A	2	49.7	56.5	56.0	56.5	43.6%	—	262.3	52.5	3/4
Total	N		630	555	437	270	164	97		—	
	N_A		331	310	261	178	107	69		—	
	n_A		171	157	120	86	42	27	603	—	
	n_A/N	3	27.1	28.3	27.5	31.9	25.6%	—	140.4	28.1	1/2
	n_A/N_A	4	51.7	50.6	46.4	48.3	39.3%	—	236.3	47.3	5/9
1-Day Prediction											
								Average (%)			
Regular		1.3	85	85	85	85	85	85			
		2.4	90	90	90	90	90	90			
		1	80	85	87	90	82	85			
		2	86	95	94	95	79	90			
		3	82	84	83	89	80	84			
		4	93	91	87	89	79	88			
Best			93	95	94	95	82	92			
Medium Range Prediction											
Regular		1.3	90	85	80	73	66				
		2.4	95	90	84	77	69				
		1	85	85	82	78	63				
		2	91	95	88	82	58				
		3	88	85	79	78	62				
		4	95	93	83	78	60				
Best			95	95	88	82	63				

NOTES: N = duration of x-days or longer of GWL
N_A = duration of x-days or longer of GWL with type I weather
n_A = type I weather on day x.

TABLE 19. EIGHT-STATION PREDICTION MODEL, DECEMBER- FEBRYARY (1960-1970)

		Prediction No.	Days 1	2	3	4	5	6	Total	Average
Group II	N	—	96	93	65	42	26	17	—	—
	N_A	—	63	62	46	31	22	15	—	—
	n_A	—	36	42	38	20	10	10	156	
	n_A/N	1	37.5	45.2	58.5	47.6	38.5%	—	227.3	45.5
	n_A/N_A	2	57.1	67.7	82.6	64.5	45.4%	—	317.3	63.5
Total	N	—	265	235	184	116	71	46		
	N_A	—	153	147	122	82	52	35		
	n_A	—	82	82	66	39	20	12		
	n_A/N	3	30.9	34.9	35.9	33.6	28.2%	—	163.5	32.7
	n_A/N_A	4	53.6	55.8	54.1	47.6	38.5%	—	249.6	49.9
1-Day Prediction										
								Average (%)		
Regular			85	85	85	85	85	85		
			90	90	90	90	90	90		
		1	82	85	90	86	82	85		
		2	89	91	95	90	85	90		
		3	82	88	90	86	78	85		
		4	93	95	94	88	75	90		
Best			93	95	95	90	85	92		
Medium Range Prediction										
Regular		1,3	90	85	80	73	66			
		2,4	95	90	84	77	69			
		1	82	85	85	74	63			
		2	89	89	89	77	58			
		3	82	88	85	74	59			
		4	93	95	88	75	59			
Best			93	95	89	77	63			

NOTES: N = duration of x-days or longer of GWL
N_A = duration of x-days or longer of GWL with type I weather
n_A = type I weather on day x.

TABLE 20. NINE-STATION PREDICTION MODEL, SEPTEMBER—MARCH (1960-1970)

		Prediction No.	Days 1	2	3	4	5	6	Total	Average
Group II	N		258	253	192	123	68	41		
	N_A		119	119	94	69	41	28		
	n_A		50	62	49	31	14	16		
	n_A/N	1	19.4	24.5	25.5	25.2	20.6%	—	155.2	23.0
	n_A/N_A	2	42.0	52.1	52.1	44.9	34.1%	—	225.2	45.0
Total	N		630	555	437	270	164	97		
	N_A		221	268	175	125	76	51		
	n_A		95	95	72	49	22	21		
	n_A/N	3	15.1	17.1	16.5	18.1	13.4%	—	80.2	16.2
	n_A/N_A	4	43.0	45.7	41.1	39.2	28.9%	—	197.9	39.6
1-Day Prediction										
								Average (%)		
Regular		1,3	85	85	85	85	85	85		
		2,4	90	90	90	90	90	90		
		1	78	88	90	89	80	85		
		2	88	95	95	90	82	90		
		3	83	88	86	90	78	85		
		4	93	95	91	90	81	90		
Best			93	95	95	90	82	91		
Medium Range Prediction										
Regular		1,3	90	85	80	73	66			
		2,4	95	90	84	77	69			
		1	78	88	85	77	61			
		2	88	95	89	77	61			
		3	83	88	81	78	60			
		4	93	95	85	77	60			
Best			93	95	89	78	61			

NOTES: N = duration of x-days or longer of GWL
N_A = duration of x-days or longer of GWL with type I weather
n_A = type I weather on day x.

TABLE 21. NINE-STATION PREDICTION MODEL, DECEMBER—FEBRUARY (1960-1970)

		Prediction No.	Days						Total	Average
			1	2	3	4	5	6		
Group II	N		96	93	65	42	26	17	—	—
	N_A		38	38	29	23	15	12	—	—
	n_A		21	26	17	12	9	8	—	—
	n_A/N	3	21.9	28.0	26.2	28.6	34.6%	-	139.3	27.9
	n_A/N_A	4	55.3	68.4	58.6	52.2	66.7%	-	301.2	60.2
Total	N		265	235	184	116	71	46	—	—
	N_A		96	92	77	54	33	24	—	—
	n_A		46	42	30	19	13	9	—	—
	n_A/N	3	17.4	17.9	16.3	16.4	18.3%	-	86.3	17.3
	n_A/N_A	4	47.9	45.7	39.0	35.2	39.4%	-	207.2	41.4
1-Day Prediction										
								Average (%)		
Regular		1.3	85	85	85	85	85	85		
		2.4	90	90	90	90	90	90		
		1	81	85	84	86	90	85		
		2	87	95	89	85	94	90		
		3	85	88	80	86	90	85		
		4	95	93	88	85	91	90		
Best			95	95	89	86	94	92		
Medium Range Prediction										
Regular		1.3	90	85	80	73	66			
		2.4	95	90	84	77	69			
		1	81	85	78	74	71			
		2	87	95	83	72	73			
		3	85	88	75	69	71			
		4	95	88	78	68	68			
Best			95	95	83	74	73			

NOTES: N = duration of x-days or longer of GWL
N_A = duration of x-days or longer of GWL with type I weather
n_A = type I weather on day x.

A further modification was introduced. A listing was obtained of the GWL systems which does not show adverse weather as defined above during their entire life time. The remaining number of GWL with adverse weather was calculated and the frequency is exhibited in the second line of Tables 18 through 21 under N_A. This breakdown has been introduced on the assumption that the forecaster may be able to distinguish between systems leading to widespread adverse weather and others which do not. The relative number of days with adverse weather observed from this new collective is shown in the row n_A/N_A. It is evident that the percentage number is higher. This should be expected as parts of the GWL types have been eliminated. Prediction chances should be higher, which is justified, since additional knowledge, available to the forecaster, is to his benefit. It is not impossible that the forecaster would be able to distinguish the two separate classes of GWL types with and without adverse weather. Elaboration on further details would lead too deeply into the actual problem of predicting the days with adverse weather, which is not the intended goal of this report.

The further section in the upper half of Tables 18 through 21 reflects the same information as discussed previously only for the combined groups I and II of the GWL types. This summary was largely taken under the provision that division into the two groups of Table 12 with higher chances for group II may not be desired by some individuals. It also answers the question that would be expected when the forecaster would not recognize a distinct GWL type. As has been pointed out already during the discussion of the separation into the two groups of GWL types, that the peak of days with adverse weather is the first day when the absolute count is examined. When the duration of the GWL is taken into consideration, the relative count varies, especially when the types are separated into classes of clear and adverse weather. If any concept of GWL types can be applied, the forecaster would learn from Tables 18 through 21 that the relative number of days with adverse weather discerns a peak later than the first day. A separation into classes with and without adverse weather would not change this fact; only the relative frequency is higher (Tables 18 through 21).

In general, the overall percentage with days of adverse weather is somewhat higher in winter than for the period September through March, and this increased percentage should enhance the prediction chances in winter. It was therefore decided to include two time periods into this report: the total from September through March and the winter season December through February.

The computation of the 1-day prediction (regular) was based on a probability of 85-percent correctness for the average n_A/N since the number of days with adverse weather is lower than for n_A/N_A. It may be more difficult to forecast these days correctly. This assumption of an 85-percent average may be on the conservative side. The average chance for the n_A/N_A group was equated with 90 percent, which may also be considered somewhat conservative under the point of view that widespread adverse weather as a large-scale phenomena could reach 95-percent prediction success.

The difference from the average was then computed for the relative number of occurrence n_A/N and n_A/N_A, and it was assumed that the maximum difference would increase the prediction chances by 5 percent. This is equivalent to equating the peak of the relative frequency of adverse weather with the maximum chance of 90 or 95 percent. The other differences were adjusted accordingly, which leads to the 1-day prediction probabilities for the four cases under consideration. The score is exhibited in the upper portion of the prediction section of Tables 18 through 21. (The numbering of the prediction models is given in the respective column preceding the chances.)

A last row was added to extract the best forecasting probabilities from any of the four cases under the assumption that the forecaster would be flexible enough to adjust the forecasting scheme to the best suitable technique. Under these postulations, the second day appears with 95-percent success-chances regardless of whether the winter season or the 7-month period is depicted or whether the eight- or nine-station models are examined. The peak at the individual models varies between the first and the fifth day.

The second evaluation is the consideration of a medium-range prediction. This means the prediction is made 1 to 5 days in advance, and a scale of decline of forecasting success for the cases one and three as well as two and four is assumed as shown in the top lines (regular) serving as the basis for the comparison. The decrease is less conservative than in the evaluation model of Table 14, but may be considered realistic enough to be achievable. Again, the differences from the average percentage as previously calculated with the maximum adjusted to 5 percent were taken and added to or subtracted from the regular (average) chances of success. As expected, the probability decreases with the increasing length of the prediction interval. It should be noticed, however, that the chances compare favorably up to the fourth day with the 1-day prediction success of today's 1-day prediction rating. The first 2 days may be seemingly high. It should be added that we are not dealing with an ordinary local forecast but with the prediction of widespread areal patterns and phenomena.

One further remark appears in order. The first day predictions do not take into account that the transition of the large-scale pattern (GWL) from one type to the next will have to be forecasted. This may decrease the chances as presented in Tables 18 through 21 for the first day, but would not affect the score for the second and subsequent days since, by then, the GWL type is well established. With the anticipated improvement in the predicting of the pressure pattern more precisely in the next decade, even the 1-day chances may be realized.

It can also be noticed that in the medium range prediction the first-day chances of the 1-day scheme have been adopted. The higher value on the first day in the reference base was necessary to establish the analytical expectation for the second and continuing days while in the actual four models the score from the 1-day model is substituted as more realistic.

The apparent contradiction of a better chance for the 2-day forecast than the first day can be explained by the necessity that the forecaster must recognize the existence of the GWL and that adverse weather displays a peak in the relative frequency later than the first day of a GWL type. Hence the forecaster knows more after the first day of existence of the GWL or could better classify the systems which last longer than 1 day. This additional knowledge is rewarded by a higher score.

It should be reiterated that the given probabilities of success for the forecast are speculative. However, the assessment is realistic under the given circumstances that the exact method of prediction is not known to evaluate precisely the prediction in the time frame 1980—1985. Another course of examination by extracting information from today's weather maps for forecasting evaluation was also not possible due to time and fund limitation. This would have answered some open questions which were left by the presented evaluation scheme. It opens up new ones, however. Thus it is not known whether in a particular instance the forecaster would rely only on weather maps, etc.

Under anticipation that the present progress in computerized forecasting of weather maps will continue, the speculative figures of success seem justified. It is believed that the assignment of an average score to the average number of days with adverse weather is reasonable. The success should increase with increase of the relative frequency of the event to be predicted, which is in accordance with the points of view presented in Section III.1.

It should be finally mentioned that various authors have developed excellent schemes of skill scores (e.g., Reference [10]) which were not applicable in this particular case, however.

Section IV. CONCLUSION

The duration of adverse weather as defined by type I (Table 2) was analyzed first. The duration in hours was derived from three hourly records, and a Weibull model was fitted to the frequency distributions. The median (50-percent probability) fluctuates between 4-1/2 to 8 hours in the winter season as demonstrated by five selected stations from Central Europe. It has been further established that 10 percent of the cases lasted longer than 16 to 24 hours.

Although adverse weather can begin at every hour, 45 percent of the cases show preference between 03 and 06 hour in the morning, while adverse weather seems to end between 06 and 09 in the morning in about 50 percent of the cases. It must be added, however, that this annual summary exhibits a distinct seasonal shift to earlier hours in summer and later hours in winter in unison with the shift of the minimum temperature due to change in the length of the night.

The problem of the duration of days with adverse weather was pursued with a midnight and 18-hour division of the day. Both procedures led to equivalent results, and in 50 percent of the cases adverse weather lasts less than between 2 to 2-1/2 days in the winter season, but in 10 percent of the cases adverse weather exceeds between 4 to 7 days in the winter months. This result is based on single-station analysis.

The outcome of the percentage frequency is virtually the same when the average of simultaneous occurrence of adverse weather for a number of six-station combinations is analyzed, but the number of cases drops considerably. This decrease of the number of cases runs parallel with earlier findings that probability of adverse weather reduces for simultaneous occurrence over an extended area with increasing area [1].

The second part of this study was directed towards the assessment of a probability score for the prediction of adverse weather. It was pointed out that an objective score can only be calculated when the precise method of forecasting is known. In our case we need to know the forecasting tool in the time frame 1980—1985. All given values must, therefore, be considered speculative but would be achievable in the opinion of the author. They may be more on the conservative side rather than being overly optimistic.

For proper evaluation the relationship between large-scale weather pattern (GWL) and adverse weather has been derived. When the seemingly high figure of 95 percent of success for the forecasting of adverse weather on the second day during the existence of certain GWL types is considered, someone may doubt that this high score is conservative. In defense one must point towards the goal of an areal forecast and the predicting of large-scale patterns and phenomena which today already have a much higher degree of accuracy than the localized forecast. Under this aspect, the 95 percent is not too high and assumes even no improvement in the coming decade.

Several models of prediction have been introduced with varying chances of success. It has been demonstrated that grouping of the GWL types will increase forecasting chances, especially when a separation into systems could be found with and without adverse weather during the existence of a GWL type.

The evaluation was based on two forecasting goals, a 1-day prediction and a medium-range prediction up to 5 days. In summary, the 1-day prediction appears most successful on the second day of the GWL type. This result coincides with the fact that the transition between one GWL type to the next does not enter the picture on the second day.

It is evident that the probability score declines with increasing time from the prediction point. The given numbers in Tables 18 through 21 disclose, however, that the medium-range prediction may compare favorably for the first 3 to 4 days with scores which are expected today for the local scale. Under consideration of the improvements made in the last years in medium-range prediction and the anticipated research results in this decade, the given scores should be achievable.

It should not be overlooked that 170 systems with adverse weather in GWL group II in the period September—March or 63 in winter (December—February) mean the existence of two systems per month in the average. Even the 310 and 147 cases of all types of GWL systems in the quoted reference period, which lasted longer than 2 days and showed adverse weather during their existence, provide only an increase of 4 to 5 per month. These average figures may be exceeded in 1 year but also undercut. The systems occur frequently enough, however, to be accounted for.

Some features of the large-scale weather patterns and a map of the stations are given in the Appendix.

Appendix. GROSSWETTERLAGEN ASSOCIATED WITH TYPE I WEATHER

This appendix is added for the benefit of the reader who is unfamiliar with the referenced reports on the GWL, and provides some background information on the association of the GWL with the weather types as defined in Table 2.

Eight of the twelve stations were depicted, and contingency tables for the 12 GWL's versus major weather types have been compiled for the winter season (December—February) and two time periods. The morning hour of 06 was chosen since it is close to the conditions where most frequently adverse weather occurs. All three hourly intervals were combined and averaged to delineate the conditions of the day. The information has been condensed into Table A-1.

When the average is determined where the maximum frequency appears at each GWL type, we find that six GWL types for the 06 hour and eight for the all-hour combination display the type IV category, i.e., clear weather. This is not surprising since this category comprises the most data in the single station count, and the summary is, therefore, in agreement with the findings of an earlier report [1]. If the class with the highest frequency per GWL would follow only a random distribution, one would even expect that more than eight GWL's would show the maximum for class IV weather.

High but not contradictory to the anticipated behavior of weather types is the fact that in the average four types for the morning hours and three for the combination of the hours disclose maximum percentage counts in type III (overcast). These are largely westerly to northwesterly situations, and the result agrees with physical behavior of the GWL types as one would expect.

We discover, however, that two GWL types for the 06 hour and one for the all-hour combination show a maximum frequency of type I, adverse weather. A closer perusal reveals that these two GWL's are the high pressure over Central Europe (H) and the southeasterly flow (SE).

Since class IV is the biggest unit with the most observations, the deviations from this pattern in the individual GWL types become statistically significant, and it can be concluded that the occurrence of type I weather is not pure random play.

A thorough statistical analysis would have to take into account the unequal occurrence of the GWL types and the imbalance of the distribution within the weather classes I through IV. These checks are time consuming and expensive if performed on all sets of contingency tables even if a simplified method by Haberman [11] is utilized. Since a spot check proved a significant nonrandomness of the contingency, the testing of the entire set was not considered to be important. It was rather inferred that nonrandomness at one station may be interpreted that it exists at the other stations, too. This fact is supported by the results in Section III, where grouping of the GWL into two categories could be based on differences of physical conditions. The waiver of the entire statistical test is not a critical factor influencing the outcome of this study. It can be performed when the need arises and the benefit warrants the expenditure in costs and time.

It may be added that in Section III one group of GWL types emerged having adverse weather on the first day. The frequency gradually decreases with increasing length. This type comprises westerly to northwesterly flow, the types related with class III weather. Although cloudy most of the time, the total area is not covered by adverse class I weather. Examples of the three types most frequently occurring are exhibited in Figures A-1, A-2, and A-3 with North, West, and Northwest.

The second group of systems comprises the GWL types related to adverse weather which by and large lasts for a few days or develops after existence of the GWL. As previously mentioned, the high pressure over Central Europe (H) and the southerly flow situations (SW, S, SE) are predominately the situations where adverse weather develops. As concluded from the contingency table (Table A-1) one would expect that the SE types would play a larger role in the study presented in Section III. One can readily see, however, that the SE type is not very frequent; hence, the S type is listed in second place in Table 12.

One may first think that the high pressure situation associated with adverse weather over Central Europe is a contradiction to the expected fair weather in high pressure areas. It should be pointed out that high pressure occurs with cold air influx which leads in winter time in Central Europe often to widespread reduction of the visibility in the morning hours or to formation of low clouds. Thus, the combination of meteorological effects such as stagnant air, slow movement, gliding of warm air over cold air, etc., produces adverse weather.

Examples of GWL for the second group are given in Figures A-4 through A-7 with high pressure over Central Europe, South, Southwest, and Southeast. More details can be found in the pertinent literature.

It may be reiterated that adverse weather as associated with certain types of GWL supports the conclusion that a good forecaster will find certain rules to predict adverse weather, provided weather maps as constructed by the present method of numerical prediction or equivalent tools would be available.

The station locations are given in Figure A-8.

TABLE A-1. ASSOCIATION BETWEEN GWL AND MAJOR WEATHER TYPES (IN PERCENTAGE) IN WINTER (DECEMBER–FEBRUARY)

	Bitburg										Sembach									
	06					All Hours					06					All Hours				
	I	II	III	IV	N	I	II	[illegible]	IV	N	I	II	III	IV	N	I	II	III	IV	N
N	12.4	9.1	40.5	38.0	319	11.0	9.3	[illegible]	42.5	2531	15.0	9.2	35.8	41.0	293	10.4	9.9	35.2	44.5	2216
NW	19.0	11.0	50.0	20.0	100	15.9	9.2	46.0	29.0	817	18.1	7.9	44.4	29.6	88	14.3	11.6	38.2	35.9	696
W	26.6	5.0	51.0	17.4	362	23.2	4.6	51.6	20.6	2872	11.7	4.7	54.3	29.3	343	10.2	5.2	55.3	29.3	2657
SW	26.7	5.2	28.8	39.4	135	17.7	7.0	30.4	44.9	1080	15.5	3.9	26.4	54.2	129	10.9	6.6	25.7	56.8	1006
S	22.4	9.9	30.8	36.9	111	17.3	8.7	31.3	42.7	888	15.0	13.0	23.0	49.0	100	12.9	15.2	23.6	48.3	729
SE	41.8	7.3	20.0	30.9	55	22.1	13.9	20.4	43.6	447	38.7	15.9	15.9	29.5	44	28.0	15.2	18.8	38.0	297
E	19.4	8.4	32.8	39.4	155	11.7	9.2	31.6	47.5	1240	17.9	10.3	28.2	43.6	145	12.4	17.4	24.8	45.4	1073
NE	14.0	8.0	40.0	38.0	50	9.8	8.2	41.9	40.1	400	14.8	12.8	42.5	29.9	47	14.1	15.2	38.3	32.4	376
H	29.4	9.5	18.1	43.0	265	26.2	9.5	17.4	46.9	2107	29.9	17.3	13.8	39.0	231	24.7	17.8	14.8	42.7	1783
L	2.9	40.0	40.0	17.1	35	8.6	25.3	35.0	31.1	280	17.4	21.7	30.4	30.5	23	17.6	26.3	23.0	33.1	148
Ww	29.4	13.5	43.3	13.5	37	27.1	9.2	41.1	22.6	296	31.0	10.3	31.0	27.7	29	15.0	11.2	41.0	32.8	232
U	20.7	17.2	34.5	27.6	29	14.7	14.6	40.5	30.2	232	18.3	18.6	33.4	29.7	27	18.6	15.7	31.9	33.8	204
	Frankfurt										Stuttgart									
N	9.8	11.6	30.1	48.5	369	6.2	16.0	24.4	53.4	2947	8.4	19.4	32.2	40.0	370	6.6	19.1	30.7	43.6	2950
NW	7.2	12.2	38.9	41.7	139	6.9	14.5	35.9	42.8	1112	8.7	7.2	43.5	40.6	138	6.9	9.3	43.8	40.0	1104
W	9.7	7.8	36.0	46.8	472	8.4	8.9	34.4	48.3	3775	2.9	4.2	28.4	64.5	472	2.4	5.6	28.0	63.9	3775
SW	24.1	20.0	15.2	40.7	145	17.9	21.7	15.5	45.0	1159	9.6	8.3	9.5	72.4	145	6.6	10.3	8.1	75.0	1160
S	8.9	14.1	28.1	48.9	135	8.9	18.8	22.3	50.0	1080	6.6	20.0	15.6	57.8	135	6.6	21.6	12.9	58.9	1080
SE	12.7	11.1	36.5	39.7	63	8.8	17.4	32.4	41.5	504	14.3	20.6	23.8	41.3	63	10.3	19.6	21.7	48.4	504
E	3.8	15.1	25.7	55.4	179	4.7	16.5	23.2	55.6	1432	12.8	17.9	33.0	36.3	179	10.3	22.6	27.7	39.4	1431
NE	1.6	21.3	36.1	41.0	61	2.8	20.3	32.6	44.3	488	19.6	21.3	49.3	9.8	61	15.7	23.0	45.1	16.2	488
H	23.3	17.3	20.9	33.5	311	21.0	22.1	16.7	40.2	2488	25.4	20.9	20.9	32.8	311	15.5	25.6	17.2	41.7	2488
L	10.0	20.0	42.5	27.5	40	9.9	21.6	30.6	37.8	320	10.0	20.0	32.5	37.5	40	7.5	28.1	25.7	38.7	320
Ww	19.1	21.5	26.2	33.3	42	16.1	21.8	25.6	37.5	336	7.2	11.8	28.6	52.4	42	5.4	12.2	28.8	53.6	336
U	10.3	13.7	34.5	41.4	29	11.3	16.8	26.3	42.5	232	10.3	20.6	34.5	34.6	29	10.4	13.4	32.7	43.5	232

TABLE A-1. CONCLUDED

	Berlin										Hannover									
	06					All Hours					06					All Hours				
	I	II	III	IV	N	I	II	III	IV	N	I	II	III	IV	N	I	II	III	IV	N
N	11.6	17.1	36.0	35.3	369	8.9	17.1	34.4	39.6	2945	19.0	14.6	33.6	32.8	327	17.9	15.0	33.0	34.1	2632
NW	11.5	10.0	53.2	25.2	139	7.0	8.8	49.8	34.4	1112	18.4	5.9	31.9	43.7	135	14.6	8.4	40.6	36.4	1075
W	6.8	10.4	41.4	41.4	471	5.7	8.6	40.2	45.5	3767	12.7	6.7	44.2	36.4	450	9.1	7.7	44.7	38.5	3569
SW	15.9	13.8	18.6	51.7	145	9.4	11.2	19.0	60.4	1160	8.4	13.0	29.8	48.9	131	9.0	11.7	25.4	53.9	1027
S	14.7	28.2	15.6	41.5	135	11.3	25.4	14.6	48.7	1080	16.8	26.7	18.3	38.2	131	14.2	28.7	15.3	41.6	1040
SE	19.0	35.0	22.2	23.8	63	14.1	26.2	24.6	35.1	50[illegible]	27.1	27.1	18.7	27.1	59	20.1	32.1	19.4	28.4	462
E	11.7	20.7	33.6	34.0	179	7.4	18.0	31.9	42.7	1432	18.5	13.9	26.6	41.0	173	13.7	16.1	29.6	40.6	1367
NE	14.8	13.1	44.2	27.9	61	10.1	15.4	42.7	31.8	487	27.5	13.8	32.8	25.9	58	18.8	19.8	29.1	31.5	464
H	27.6	19.6	29.6	23.2	311	21.3	18.3	29.1	31.3	2487	29.2	26.4	19.6	24.8	270	24.8	26.1	17.9	31.2	2163
L	20.0	35.0	10.0	35.0	40	9.6	32.8	23.2	34.4	320	18.9	21.6	27.0	32.4	37	16.0	22.0	25.3	36.7	300
Ww	16.7	23.8	21.4	38.1	42	17.9	15.7	21.8	44.6	336	14.6	26.9	17.1	41.5	41	16.1	25.0	18.9	40.1	324
U	13.7	13.8	38.0	38.5	29	10.8	17.3	36.1	35.8	232	50.0	11.5	19.2	19.2	26	26.1	17.2	27.5	29.2	222

	Hof										Furstenfeldbruck									
	I	II	III	IV	N	I	II	III	IV	N	I	II	III	IV	N	I	II	III	IV	N
N	22.0	24.2	39.4	14.4	285	18.7	23.1	25.8	22.2	2061	11.8	17.2	25.8	45.2	93	8.9	16.8	29.7	46.6	743
NW	21.2	16.8	49.6	12.4	113	20.6	14.5	45.7	19.2	778	7.3	6.1	43.9	42.7	82	8.7	9.9	38.9	42.7	656
W	19.8	8.2	52.8	19.2	344	20.1	8.8	47.9	23.2	2410	6.3	3.9	16.5	73.3	206	3.3	3.9	20.8	72.2	1648
SW	24.7	16.5	26.8	32.0	97	23.6	12.3	26.6	37.5	679	26.1	8.7	2.2	63.0	46	27.7	10.4	8.2	53.8	368
S	18.0	23.8	33.4	24.8	105	18.1	25.0	28.5	28.4	752	40.7	13.6	15.3	30.4	59	34.1	20.1	13.2	32.3	472
SE	30.1	26.4	22.7	20.8	53	28.3	23.0	20.8	27.9	390	56.0	12.0	12.0	20.0	25	50.0	19.0	15.5	17.5	200
E	34.3	22.2	26.4	17.1	140	29.0	25.9	24.3	20.8	992	23.8	11.2	30.0	35.0	80	14.9	18.1	28.1	38.9	638
NE	40.0	24.5	26.7	8.8	45	37.0	23.6	27.9	11.5	305	16.7	27.8	38.9	16.7	36	17.4	19.5	40.0	23.3	288
H	34.5	20.6	18.7	26.2	214	30.9	20.3	17.4	31.4	1518	35.8	11.9	22.9	29.4	109	28.5	15.4	18.8	37.3	872
L	16.7	26.7	43.3	13.3	30	21.1	23.4	35.8	19.7	218	22.6	13.6	22.7	40.9	22	14.2	19.4	24.4	42.0	176
Ww	25.0	21.9	37.5	15.6	32	15.9	19.5	38.1	26.5	226	13.5	13.6	22.7	50.0	22	7.3	18.8	22.1	51.7	176
U	38.4	15.4	30.8	15.4	26	26.4	16.2	35.2	22.2	185	--	--	--	--	2	--	--	--	--	16

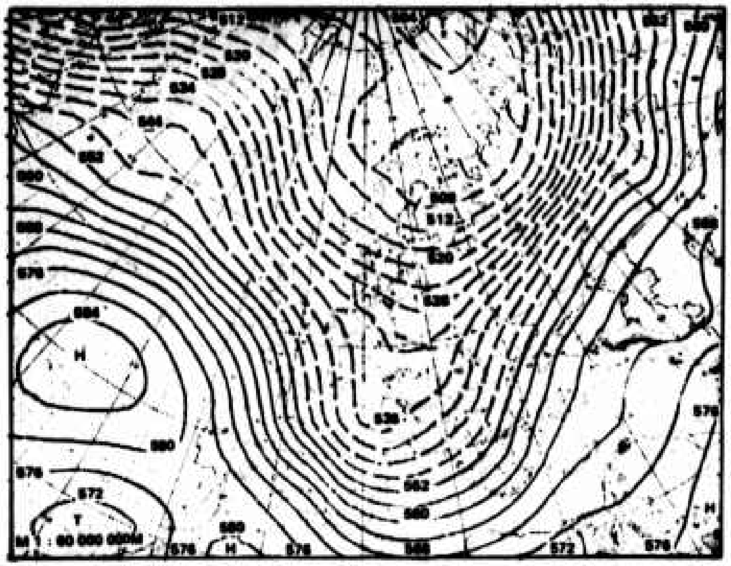

Figure A-1. North (trough over Central Europe), 20-21 November 1971.

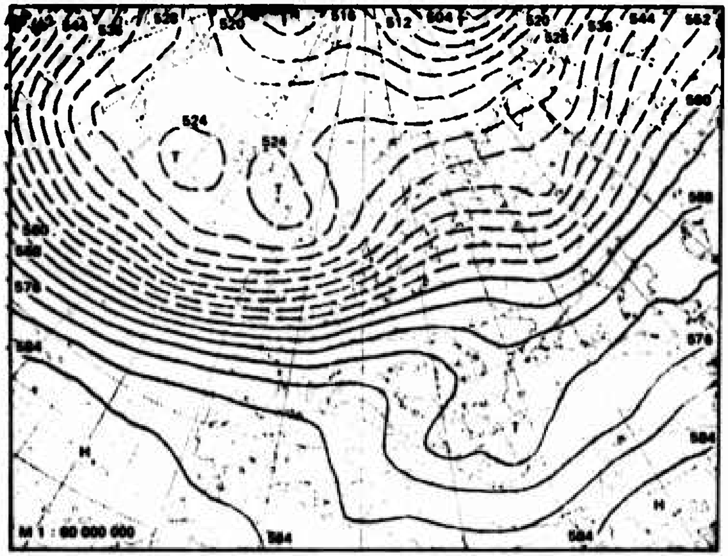

Figure A-2. West (trough over Central Europe), 18-20 October 1971.

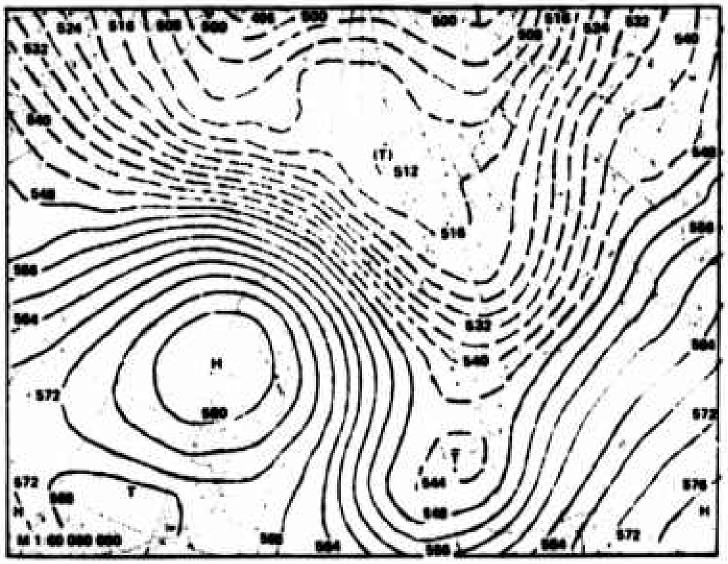

Figure A-3. Northwest (trough over Central Europe), 10-12 December 1971.

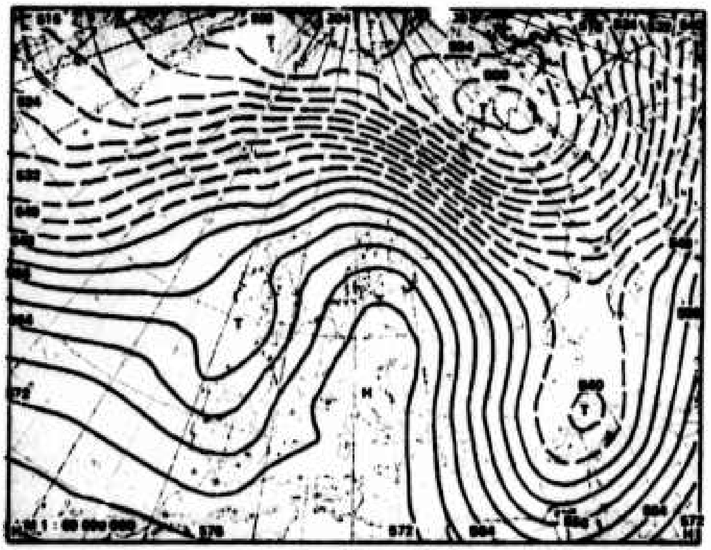

Figure A-4. High pressure over Central Europe, 11-13 December 1970.

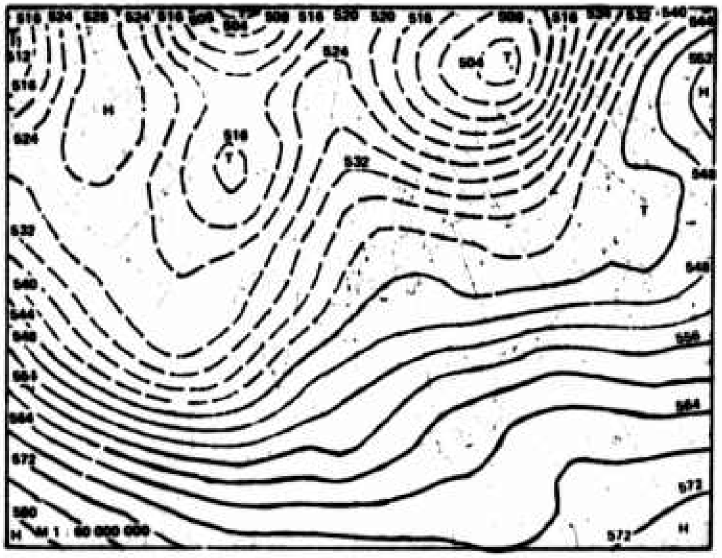

Figure A-5. High pressure over Central Europe, 8-14 January 1970 (South).

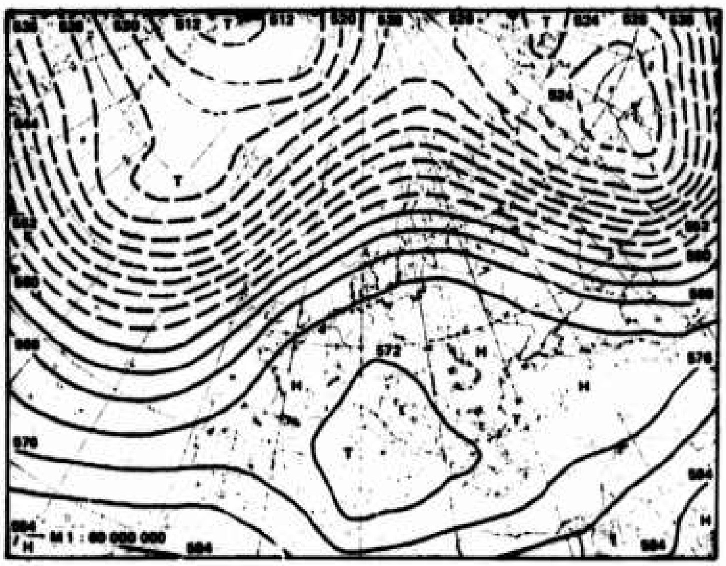

Figure A-6. High pressure over Central Europe, 14-17 October 1970 (Southwest).

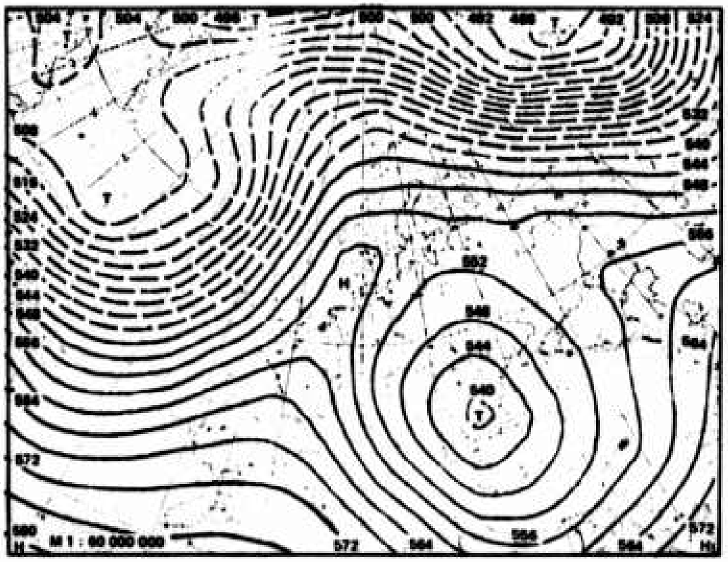

Figure A-7. High pressure over Central Europe, 19-22 January 1970 (Southeast).

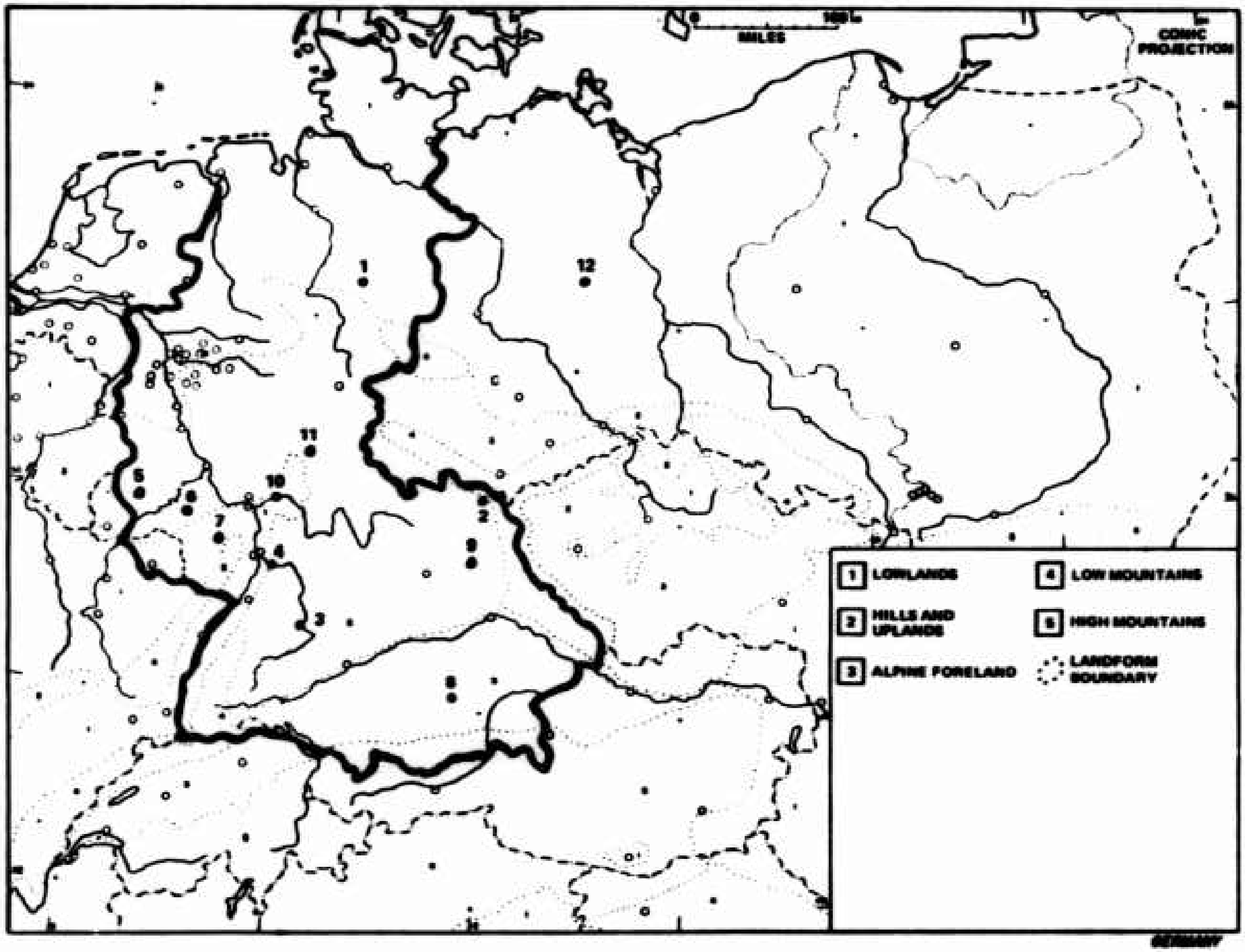

Figure A-8. Station locations.

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